The experimental test of the coupled moderator performance at LANSCE

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Abstract

We present the results of a performance test of the novel liquid H_2 moderator installed at Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) at LANSCE. The results include the determination of the moderator time average flux and peak flux, determination of the time structure of the pulse as well the control of the life-time of the supermirror neutron optics placed close to the source. The data show that the coupled moderator at LANSCE provides the highest cold neutron flux (both average and peak) at pulsed spallation sources in the world and that the peak intensity of the pulse exceed the intensity of the ILL cold neutron source by factor of 2.5 in average over the wavelength range measured.

1. Introduction

A decoupled neutron moderator typically consists of the moderator container filled with some special material, a reflector around it, a number of neutron absorbing liners, separating the moderator from reflector, and eventually poison plates placed inside of the moderator. In the case of a coupled moderator (Fig.1) all of decoupling materials, like liners and poison are removed from the moderator system. It results in higher number of neutrons coming from the moderator in longer pulses.

The first experimental work on coupled moderators we know of was performed by J. Carpenter et al [1] in the late seventies. In this work liquid H_2 moderator was tested in two coupled and decoupled options. It was pointed out, that the coupled moderator produces by about a factor 3 more intensity of low energy neutrons. However, for different reasons decoupled moderators dominated target configurations at pulsed sources for a number of years.

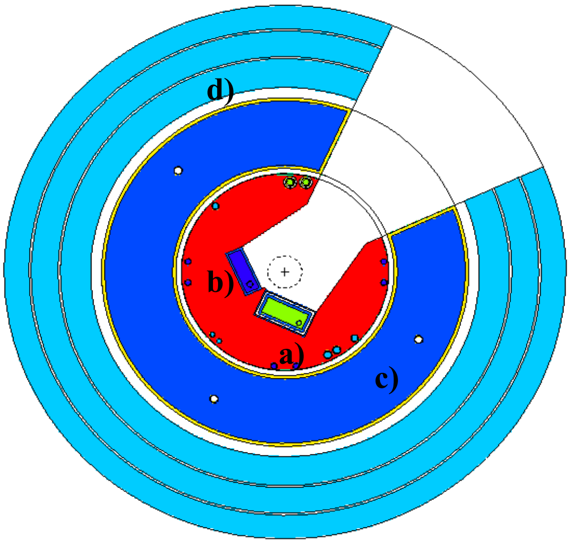

Figure 1. The scheme of the liquid H_2 coupled moderator layout at LANSCE: a) liquid H_2 coupled moderator; b) H_2O partially coupled moderator; c) Be-reflector, d) Pb-reflector

The research on coupled moderator applications intensified in the last decade in particular motivated by the developments of the Long Pulse Spallation Sources concept. One of the driving forces was the group lead by Gary Russell at Los Alamos [2], [3]. A liquid H_2 coupled moderator designed by this group has been installed at Manuel Lujan Neutron scattering Center for beam lines 12 and 13 in 1995. The moderator has dimensions of 13 x 13 cm, it is 5 cm thick and is surrounded by the composite Be-Pb reflector (fig.1). According to the calculations [3] one expected a factor of 6-7 gain in intensity compared to the fully decoupled version. The first experimental test of moderator performance took place in January 2003 with aim to measure the brilliance and time structure of the neutron pulse as well as the performance of the supermirror optics placed closed to the source and to test the new data collection procedure – event recording. Here we present the first experimental results of the test.

2. Experimental details

For the test purposes we used the existing layout of the shielding of flight path 12 (FP-12) with an addition of the detector cave. During the test the pulsed spallation source at the Lujan Center has been steadily operating with a proton current of 117 μA (c.a. 94 kW) at 20Hz.

The test consisted mainly from two parts: the measurement of the neutron flux and measurement of the time structure of the pulse; we had two different experimental configurations accordingly.

a) Measurement of the flux. The experimental set-up of the measurement of the flux is shown on the Fig.2a. Point zero indicates the surface of the liquid H_2 moderator. Rectangular (9.5 cm x 9.5 cm) supermirror neutron guide starts at 1.3 m from the source and it is 8 m long. A pinhole of 1mm diameter has been placed in the Li-plastic plate surrounded by the concentric iron and polyethylene pieces to reduce the background at 11.9 m distance from the source.

The detector was positioned at the 14.5 m distance from the moderator. We used two different options to detect the neutrons. First one was a round 2 mm diameter Li- scintillator. On the front of the detector we positioned a second pinhole of 2 mm diameter.

Second option included a position sensitive area He-detector, kindly provided by KFKI/Hungary. The detector has a rectangular shape with a size of 20 x 20 cm and the position resolution of 1 mm^2. A useful feature of the detector was the ability to work in time-of-flight option. He-detector has been mostly used for the imaging of the guide and moderator and the primary determination of the flux, while the Li-detector has been used for

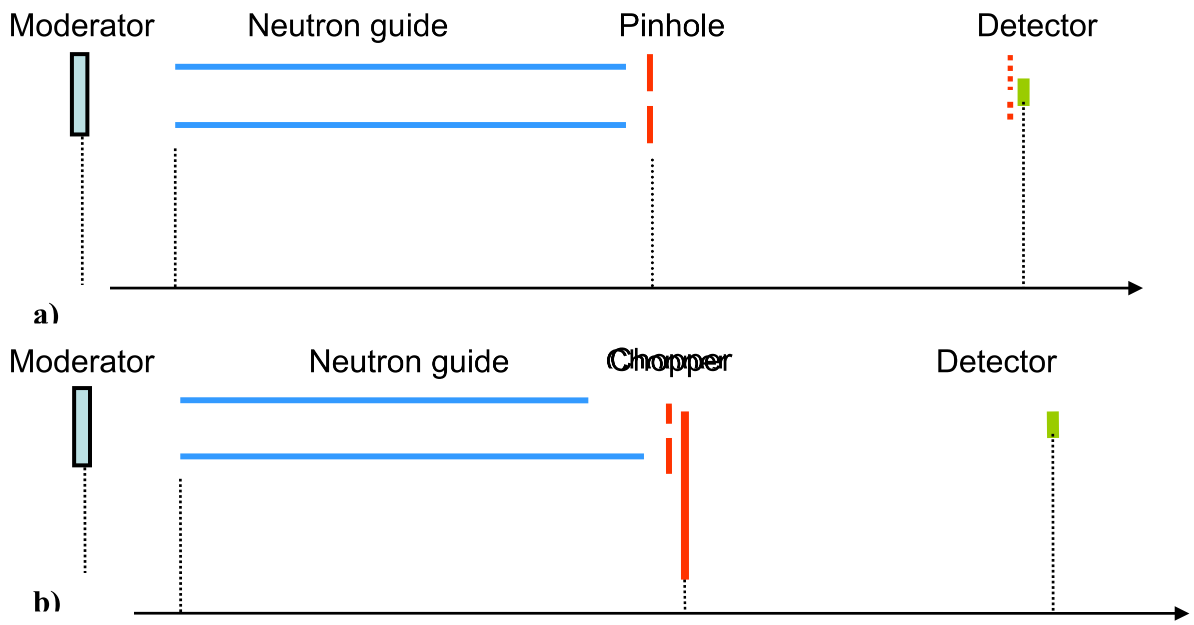

Figure 2. a) experimental configuration for the moderator flux measurement; b) experimental configuration for the pulse shape determination

the calibration of the He-detector and more precise determination of the moderator brilliance.

b) Measurement of the pulse shape. The experimental set-up for the pulse shape measurement (Fig.2b) was very similar to that of the flux determination with the difference that just behind the pinhole diaphragm at the exit of the neutron guide we introduced a disk chopper, loaned to us by Hahn-Meitner-Institut Berlin/Germany. The chopper was made from the aluminum disc coated by Gadolinium paint. Since the chopper had no capability to be synchronize to the source we went the opposite way and let the chopper run asynchronically to the source with 13 Hz repetition frequency. The diaphragm has a dimension of 1.8 mm diameter and was placed very close to the chopper face. The chopper slit was 1.78 mm wide. For the neutron detection we used the Li-detector described above.

3. Data Collection and Treatment

a) Flux determination and homogeneity measurement of the moderator. The flux determination has been based on Louville's theorem: the phase-space density ρ is constant along particles trajectories in the conservative force field. The system of the pinholes in set-up #1 defines the trajectory of the particles. Since there are losses caused by the air-absorption and detector efficiency the brightness measured at the detector is the lower limit of the brightness at the moderator surface. The neutron counts have been collected as a function of time and afterwards have been transformed to a function of the wavelength. In addition we have corrected for the air-absorption and detector efficiency.

An additional goal of this part of the experiment was to test the performance of the supermirror optics placed close to the source after one year of irradiation. For this purpose we took the image of the moderator and its reflected image on the guide walls as a function of the wavelength

b) Pulse shape measurement. We used a prototype of the event recording technique for the data collection. The neutron intensity has been recorded as a function of two parameters: chopper phase (i.e. the chopper opening time) and the neutron detection time, both with respect to the source proton pulse. Since this two values are correlated to each other we observe the signal only when the chopper phase and the neutron detection time correspond to the same velocity (Fig.3). The background has been measured with the chopper closed, scaled to the spectra and subtracted.

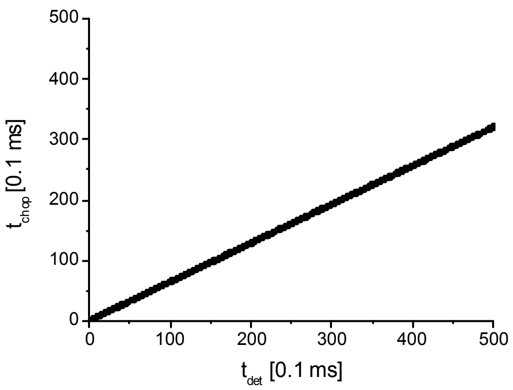

Figure 3. domain of neutron counts above background in the t_{det} and t_{chop} parameter space.

The recorded intensity has been converted to the intensity as a function of the neutron wavelength and emission time τ_{em}. The constant neutron velocity is observed when the time difference between the neutron detection time and a chopper phase is constant. The velocity of neutrons was calculated accordingly:

$$V_{neutrons} = (L_{det} - L_{ch}) / (t_{det} - t_{ch}) \quad (1),$$

where L_{det} and L_{ch} indicate the position of the chopper and detector respectively, t_{det} is the neutron detection time and t_{ch} stands for the chopper phase time. Emission neutron time has been calculated using the formula:

$$t_{em} = t_{det} - L_{det}/V_{neutrons} \quad (2).$$

The resolution of the chopper has been first numerically calculated as a convolution of two contributions: the rotating chopper slit and a round diaphragm; afterwards it has been approximated with the gaussian for simplicity of the fitting (fig.4). The HFWM of the gaussian, i.e. the resolution of the chopper, was equal to 186 μs. The resolution of the detection and recording of the chopper phase was equal to 100 μs.

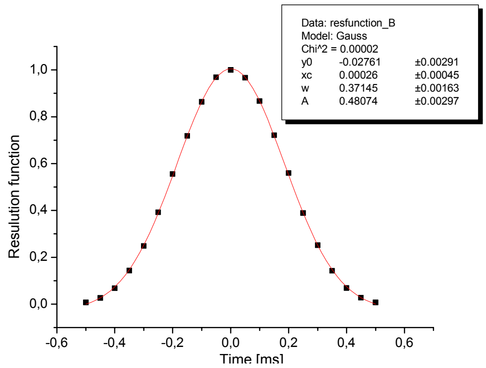

Figure 4. Numerically calculated chopper resolution function (solid circles) fitted by Gaussian model (line)

4. Results

a) moderator homogeneity and performance of the supermirror guide The images of the moderator and the guide have been taken with a position sensitive He-detector at different wavelengths. The area of the moderator seen trough the pinhole system has been limited by the guide dimensions to about 10 x 10 cm. At the detector the image of the moderator has been reduced to the 2.2 x 2.2 cm size.

Fig. 5a shows the image taken at λ=0.8Å. The neutron guide does not influence flight directions of neutrons with such short wavelength and the image taken contains only the image of the moderator. It can be clearly seen that the intensity of the moderator is mostly

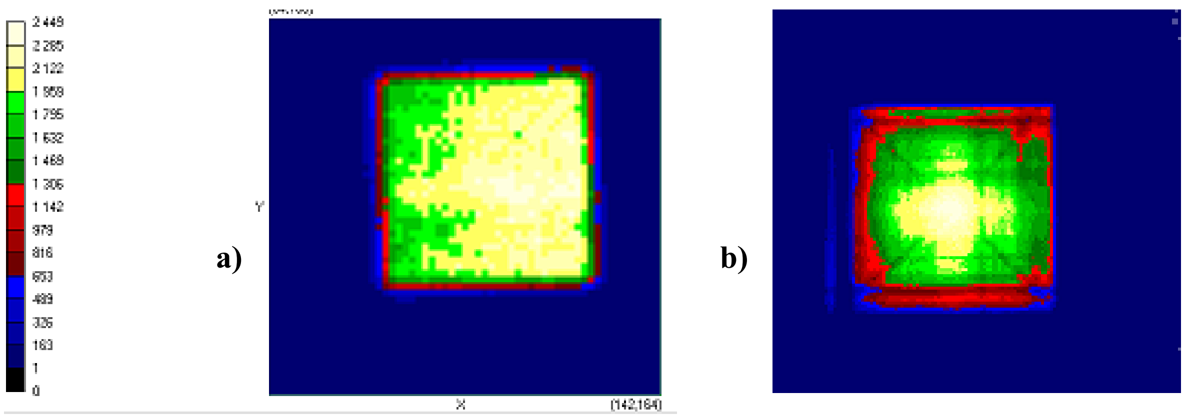

Figure 5. a) the image of the moderator taken at λ=0.8Å (slow-down regime); b) image of the moderator in the center, surrounded by its image reflected by the guide system at 2.6Å (thermalization regime). The image is centered and symmetrical, showing good illumination of the guide. Please note, that the magnification factor is different for figures a) and b) for better view.

homogeneous, however about 15% lower intensity is observed on the top of the moderator, corresponding to the right in the image. This can be explained by inhomogeneous illumination of the moderator by the target in slow-down regime. At longer wavelength in thermalization regime (fig.5b) such inhomogeneity disappears and the image observed is symmetrical.

Fig. 5b shows one of such images taken at λ=2.6Å. At longer wavelength the image of the moderator (in the center) is complemented by its reflections on the guide walls. The results show fully symmetrical and well centered, rather homogeneous pictures which witness the good illumination of the neutron guide. One of our particular subjects of interest was the performance of the supermirror optics placed close to the source. The neutron supermirror guide at the beamline 12 starts at 1.3m from the source and is about 8 m long. The supermirror coating is known to be very sensitive to the temperature and could be eventually influenced by the radiation. The in-pile section of the guide has been installed in February 2001, and the operation power of the Lujan Center for the last six month was 100 kW. The reflectivity was measured as a ratio between the intensity of neutrons reflected by the guide to the intensity coming from the moderator direct view. The results show, that the quality of the Ni/Ti supermirror remains unchanged over two yearly run cycles .

b) Moderator brightness. Fig.6 demonstrates the moderator brightness compare to the brightnessses of the ILL cold and thermal source and the partially-coupled H_2O moderator, installed in Lujan Center on the Flight Path 11.

It can be clearly seen that the time average brilliance of the coupled H_2 moderator is about 2% of the ILL cold neutron source. The intensity gain of the H_2 moderator compared to the partially coupled H_2O moderator ranges between factors 1.5-2 depending on the wavelength. For the function of many types of neutron instruments the most important characteristics however is not the time average brilliance, but the peak flux of the pulse. The intensity of the peak flux has been determined using the data of the pulse shape. The observed gain of intensity ranges from 1.8 at λ=9.7Å to 3.3 at λ=4Å and 4.3 at λ=3Å (Fig.6). *This shows that Lujan Center is the most powerful pulsed cold neutron source in the world.*

c) Time structure of the pulse. Using the experimental set-up described before we could collect and analyze the data in the 1.2-10 A range. This energy range corresponds to the thermalization regime of the moderation, i.e. during the moderation process neutron can experience more then one collision with particles in moderator and in the case of the coupled moderator – with particles in the reflector. The shape of the moderator pulse in the thermalization regime is empirically described by combination of several exponential functions. For the pulse shape analyze we used the following model:

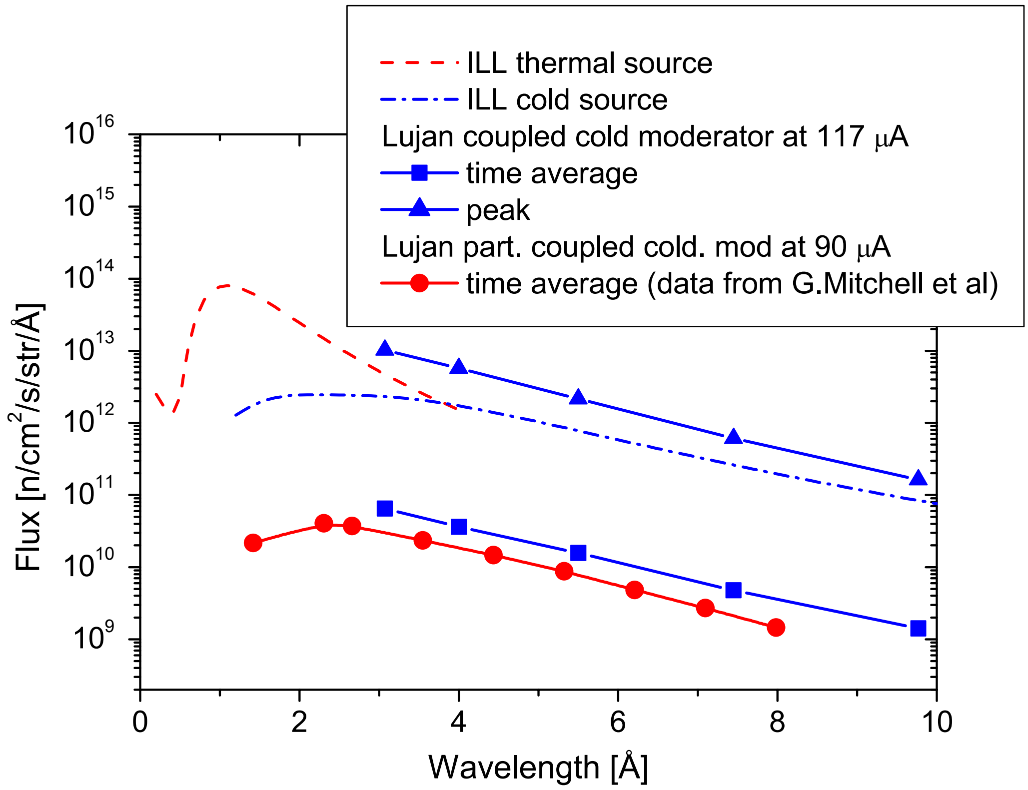

Figure 6. Time average brilliance and the peak flux of the pulse of the liquid H_2 coupled moderator at LANSCE, measured as a function of the wavelength and compared to the fluxes of ILL cold and thermal sources. Circles and lines indicate the data obtained for the partially coupled H_2O moderator.

$$F(t,\tau_i) = \frac{\exp(-t/\tau_i) - \exp(-nt/\tau_i)}{n/((n-1)\tau)} \qquad (3),$$

with n=20. The experimental data $I(\lambda,t_{em})$ have been fitted by the convolution of the resolution function of the chopper $R(\lambda,t)$ and the superposition of the two such functions (3):

$$I(\lambda,t_{em}) = R(\lambda,t) \otimes (k_1 F_1(t,\tau_1)+k_2 F_2(t,\tau_2)) \qquad (4)$$

Fig.6 shows the experimental data taken for four different wavelengths, fitted with the model (4). At the short λ=3Å wavelength data can be fitted using only one exponential function with the decay time constant τ_1 = 270 μs. With increasing of the wavelength to 5.5Å and broadening of the pulse tail a second exponential function with the decay time τ_2 of about 600 μs appears in the fit. Surprisingly, the further increase of the wavelength does not result in the

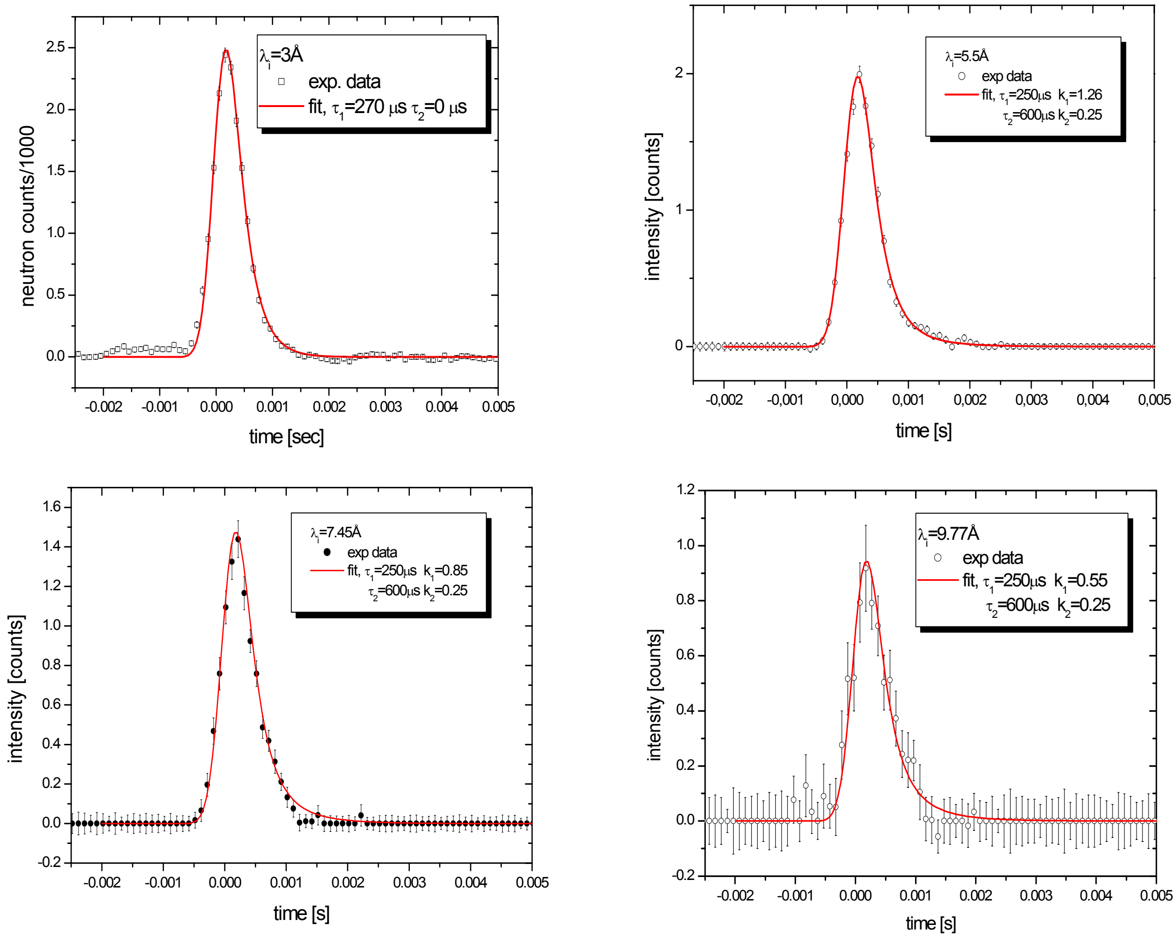

Figure 7. Experimental data of the pulse shape (points) and fit using (3) and (4) indicated by lines.

longer decay time, but lead to the increase of the weight of the second function. The relative weight of the two function relative to each other changes from 5:1 at 5.5Å to about 2.2:1 at 9.77Å.

5. Conclusions

Future progress in neutron scattering research depends on our capability of making spallation sources competitive and superior to reactors. The important step in this direction is the development and installation of the coupled moderators, designed to provide more intense neutron beam.

In this publication we report the first experimental results of the performance test of the coupled liquid H_2 moderator installed in Lujan Neutron Scattering Center at LANSCE and the only one worldwide by now. The data obtained indicate that the time average flux of the coupled moderator is of about 2-2.5% of the flux of ILL cold neutron source, while the peak flux intensity provided by the coupled moderator is about 1.8 to 4 times higher then ILL cold neutron source depending on the wavelength. This is the highest cold neutron intensity in the world.

Second important achievement of the test is the determination of the pulse width. The data have been successfully described by an analytical approximation using several exponential functions with two characteristic decay equal to 270μs and 600μs. The data show, that the decay times do not increase with the wavelength, starting from λ=5Å, however the ration between the two component changes with the increase of the neutron wavelength.

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